The George W. Woodruff
School of Mechanical Engineering

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THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

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NASA/UNIVERSITY
ADVANCED MISSIONS SPACE DESIGN PROGRAM

AN AUTOMATED, LUNAR BRICK-MAKING DEVICE

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ABSTRACT

The process of producing lunar bricks involves sieving and conveying soil to a mixing area, combining the soil with water and lignin sulfanate, molding into shape, then releasing the finished product. The machine used to produce these bricks is portable and can be disassembled for easy transporting.

Soil is brought by the lunar walker to a hopper where it is metered out by a rotating flow-aiding device. It is then sieved to obtain a particle distribution of less than 0.6cm. Larger particles fall from the sieve side onto the surface. The sieved soil is continuously conveyed to a vertical spaced-bucket centrifugal-discharge elevator where particles are transferred to the mixing chamber at a rate of five meters per hour. This soil is sprayed with a water-lignin solution as it falls into one of four 1m x 1m x 1.5m molds. A vibrator attached to the outside base of the mold helps to assure an even distribution of the slurry.

This process ideally recovers 100% of the initial amount of water induced into the system. The molding chamber forms a vacuum which

pumps the recovered water to the storage area located at the corner of the mixing-molding unit. The bottom opens to release the finished product onto gravity rollers, then reseals itself and the process is repeated.

INTRODUCTION

The Lunar Brick-Making Machine is primarily composed of three interfaced subsystems. The first subsystem is sifting and conveying, which is responsible for providing selected soil particles to the mixing area at a given rate. The second is the mixing region, where soil is combined with the lignin sulfanate and water needed to produce the brick slurry. Molding and brick extraction form the third section. This section encompasses the actual molding of the bricks and the structure constructed with the bricks.

Due to the nature of design for the Lunar Brick-Making Machine, each section of this report is broken down by subsystem, concluding with an overall system summary.

PROBLEM STATEMENT

BACKGROUND:

A major goal of the American Space Program, and other space programs around the world, is to establish continous human habitation on the Moon. One major obstacle to attaining this goal is the production of shelters suitable for living. This obstacle is so pronounced because of the problems arising from transporting earth-madebuilding materials to the lunar surface. The problems include freight (bulk moving), cost of shipping, and replinishment of supplies. The best solution to those problems is to manufacture shelters using the moons own resources. This would involve a one-time trip bringing water and a binder (lignin sulfanate) from earth to be mixed with processed lunar soil.

The process of making bricks for the shelters requires a small amount of lignin and water mixed with a substantially larger volume of lunar soil. The machine utilizing this process is the subject of this technical report.

CONSTRAINTS:

The constraints within which this machine must operate are stringent and mostly relate to the environment on the moon. First, the device must successfully operate in the lunar environment which has temperatures in the range of ± 200 degrees centigrade. Also there is a harsh vacuum present which means there is no water or air to serve as heat absorbing or moisture producing elements. Secondly, there is a time constraint. The first shelter must be built within ten Earth days. Each moon day is approximately thirteen to fourteen Earth days. The extra three to four days are alloted for assembly and dry running of the machine. It produces one brick every 2.8 minutes, with each shelter requiring three thousand bricks to enclose a eighteen meter long cylinder with a six meter diameter. This equates to producing a shelter every 5.8 Earth days. The bricks dimensions are 1.5m x 1m x 1m. The moon weight per brick is approximately 150 pounds. Thirdly, the machine should be automated. There will be no manual operation other than assembly of the machine, use of the lunar walker to obtain the bulk soil, and construction of the shelter. No human operation is necessary in producing the brick. All metering and shut-down processes are timer controlled using switches and electronic controls (i.e. level meters, timers, and electronic eyes). Lastly, the machine is relatively easy to disassemble at one site and reassemble at the proposed site of another shelter. This minimizes the use of the walker and is more efficient when large distances between shelters are being considered.

The walls of the bin are classified as retaining walls. The pressure per meter length of the straight walls is 238 kilograms per square meter. The pressure exerted on the inclined wals is 240 kilograms per square meter. These pressures are the maximum and are assumed for a fully-loaded bin. The initial sheer stress on the walls of the hopper is 207 kilograms per square meter and will increase to 415 kilograms per square meter as the soil flows through the outlet.

The inclined walls of the hopper form a fifty degree angle with the vertical axis. This engle is the pre-determined angle of repose for lunar soil. By designing these walls at the angle of repose uniform flow characteristics are maintained thus making the flow easier to control.

Two important definitions of flow characteristics of a storage vessel are mass flow, which means that all the material in the vessel moves whenever any is withdrawn, and funnel flow, which occurs when only a portion of the material flows when any material is withdrawn. The lunar brick-making machine will operate under mass flow conditions because of the preferred characteristics of the flow which are (1) fine particles deaerate and do not flood when the system discharges, (2) density flow is constant, (3) levvel meters work more reliably, and most importantly (4) flow is uniform.

With mass flow, as with funnel flow, considerations must be made off flow not only through the bin but through the bin opening. We may assume free -flowing conditions up to the bin opening. At the bin opening the bulk soil may have a tendency to pack and thus form a length-wiose arch over the opening which will prevent flow. When the strength of the arch is less than the internal stress, flow occurs. Assuming uniform stress along the rectangular slot, a shear stress of 0.1 Newton will act vertically downwards and a normal stress of 0.1 Newton will act towards the center of the bin. These stresses are exerted along the rectangular slot for a 0.3m thick arch.

To assist in preventing arching at the opening and to provide more control over the soil flow, three sets of five rotating arms are added along the bridge of the opening. The arms rotate at 0.4 revolution pre minute to supply approximately 6 cubic meters of soil per hour. The torque necessary in each unit is 15 kilogram-meters.

The soil elevator is a spaced-bucked centrifugal discharge elevator. The center for the elevator is 4 meters and has a capacity of 76.3 metric tons per hour. The elevator is also capable of a maximum bucket speed of 91.4 meters per minute but is considerably less in actual use. The head shaft will rotate 38 rotations per minute requiring a horsepower of 12 at the head shaft. The assumed density of the soil transported is 1600 kilograms per cubic meter moving at a linear bucket speed of 45.7 meters per minute.

The sieving components are 90% efficient which indicates that the mass in will approximately equal the mass out. The motor to drive the sieves is an alternating current, constant speed motor with a synchronous speed of 3600 rotations per minute. The motor to drive the conveyor and bucket elevator will require a synchronous speed of 7200 rotations per minute.

The material selected for the bin is an aluminum alloy, Alclad 6061. The supports are of 4028 steel. The apron for both the conveyor and elevator are of mesh aluminum with reinforced edges. The buckets are of the same aluminum and the pulleys are of the same steel. A graphite lubricant is used on all moving parts.

Solid level controls are needed for determining the level of the material in the bin and to protect against jamming at the conveyor. They operate on electrical ties to the conveying system and blades, which act to start and stop the process when necessary.

SIFTING CONVEYING PROCESS

SIFTING AND CONVEYING

The initial stages of brick manufacturing begin with sifting and conveying soil needed for production. Lunar soil is brought to a $39m^3$ aluminum alloy hopper by the lunar walker. The upper section of the hopper is a $25m^3$ rectangular shaped bin, 3m x 4.6m x 1.5m. The lower section forms a trapezoid, 3m long, .9m at the lower exit, 2.1m tall, and 4.6m at the top opening, with 50^0 sloping sides. This 50^0 angle forms the angle of repose necessary to allow control of the mass flow from the bin. The unit is cast 12cm thick with a 0.9cm inner surface layer of pure (99%) commercial titanium. This maximizes strength, impact resistance, and strength-to-weight ratio.

To meter the flow from the hopper, three remote-controlled propellors, each with five blades 72^0 apart, are bolted along the bottom length of the hopper. These titanium blades are 37cm long and 5 cm tall. The propellors are spaced 1m apart, with the center one located 1.5m from either end. As the propellors rotate, lunar soil is pushed onto two consecutive mechanically vibrated titanium sieves. They are 1m x 3m and lie at a 25^0 positive sloping angle. Most soil passes first through the 3/8" mesh screen (3/8" = hole size), but larger particles roll off the sides onto the lunar surface as rejects. Sifted soil then passes through a no. 4 mesh screen (4 holes per inch). These sieves are encased in a rectangular frame which is suspended from flexible flat springs which act as shock absorbers. Vibration, induced by a reciprocating motor, agitates the soil to aid (1) the flow of rejected particles to the surface , and (2) the prevention of mesh clogging. This sieving process rids the soil of particles which may cause machine jams and provides a uniform particle distribution for manufacturing.

Sifted soil falls from the sieves to the conveying system which consists of two units, a belt conveyor and a spaced-bucket centrifugal-discharge elevator. The 1m wide belt conveyor transports soil 4.6m horizontally at a rate of $6.2m^3/hr$ into the elevator housing of the second conveyor at an angle of 50^0.

The elevator housing stands 4m tall with a 1.5m diameter verticle cross section. Inside, the aluminum conveyor is a no. 400 mesh screen with 12 buckets spaced 30cm apart to prevent interference in loading or discharging. The parabolic buckets, 36cm x 61 cm x 46 cm, are attached along the face of the belt. They are loaded with the incoming soil partly by material flowing directly into them and partly by scooping material from the boot of the casing. At the top of the conveyor soil is discharged 6m3/hr into the mixing chamber.

MIXING PROCESS

MIXING PROCESS

COMPONENTS:

1. Holding bin for lunar soil
2. Lunar soil dispensing chambers
3. Moduler dry lignin storage containers
4. Lignin/water mixing chamber
5. Lignin/water spraying system
6. Vacuum drying system
7. water recovery system

SUMMARY OF MIXING PROCESS

The mixing process begins in the upper storage bin. Soil of predetermined grain size is deposited in the upper bin. From the upper bin the soil is metered out into four 0.25 cubic meter soil dispensing units. This volume allows each dispenser to contain enough material to make one brick. The soil dispensers seal from the outside vacuum. From the dispensers, the soil is metered out into four molding chambers below. As the soil is dispensed, it is sprayed with a lignin/water mixture. The spraying provides the wetting of the lunar soil necessary for bonding of the particles. As the mixture falls into the mold, a vibrator is inserted into the mold to help disperse the soil evenly. When the mold is filled, the chamber will be sealed and evacuated. The vacuum causes the water in the brick to vaporize allowing it to dry. The vacuum used is provided by the natural vacuum of the lunar enviornment. As vapor is evacuated it is condensed back into a liquid. During the condensation process, the water is pumped out of the condenser system until the brick drtying process is complete. The process is repeated with the water being reused.

HOLDING BIN

A cylindrical storage bin mounts on top of the apparatus. The bin holds soil received from the conveyor until it can be metered into the apparatus where it will be formed into a brick . The cylinder walls are 1.35 m high. The storage bin has a truncated conical bottom. The cone has an angle of 60^0. The purpose of the cone is to aid the flow of soil into four discharge openings that are located in the circular space between the base of the cone and the base of the cylinder. The height of the truncated cone is 1.25 m. The volumetric capacity of this arrangement gives 5.55 m^3. The discharge openings are evenly spaced at 90^0 intervals about the circular space. Each discharge opening has a mechanical gate which controls the flow of the soil through the opening. The discharge openings are circular and have a diameter of 5 inches; this allow free flow of the material. The material of the bin walls is a high strength Al alloy. Aluminum has a high strength to weight ratio which is necessary to provide low mass along with the ability to withstand pressure forces that the soil exerts. A 97075 aluminum alloy provides high strength and high hardness to withstand the abrasion of the lunar soil. The thickness of the aluminum is 1 3/8 ".

LUNAR SOIL DISPENSING CHAMBER

From the holding bin, the soil is discharged into four soil dispensing chambers. Each chamber will contain enough soil to produce one brick. This volume is 0.25 m^3. The dispenser discharges soil at a rate of 200 kg/min into the mold chamber and will take approximately 2 minutes to accomplish this. The dispenser will be cubical with a rectangular pyramid hopper. The dimensions of the dispenser are 0.7m x 0.7m . 0.5m. The hopper will have a rectangular opening of 30 cm^2 (1 cm x 30 cm). The dispenser will be made of aluminum like the bin. The thickness will be 3/16". A secondary purpose of this unit is to isolate the mold chamber from the outside vacuum during mixing. This prevents loss of water due to diffusion of water vapor through the soil in the upper bin and into the moon's vacuum.

LIGNIN/WATER MIXING CHAMBER

The dry lignin and water must be mixed together before they can be sprayed onto the soil. The mixing chamber will be cylindrical. The cylinder will be 0.3 m high (≈ 1ft.) and 0.3 m (≈ 1ft.) in diameter. This gives a volume of 0.02 m^3 (5.3 gal) for the mixture. The impeller which agitates the mixture will be of stainless steel and will be of the inclined paddle blade type with a diameter of 0.2 m. The shaft that the impeller turns upon will be of stainless steel also and will be approximately 0.2 m long. The impeller will turn a t a maximum speed of 300 RPM. The power required to accomplish this is 0.25 HP. The mixing operation will last for 3 minutes. This tank will also be of aluminum, 1/4 " thick and it will be valved to allow dry lignin from the screw converor and gravity-fed liquid water from the water storage tank to enter. It will also be valved to allow the mixture to be pumped out so that it can be sprayed.

The water storage tank will be a spherical aluminum tank with a radius of 0.2 m (1/2ft) and volume of 0.02m^3. The aluminum shell will be 1/4" thick. All system water will be stored here during the lunar night. The device will not operate during the lunar night. Thermal expansion and total system water (volume standing in pipes) has been accounted for in the suggested volume.

MODULAR, DRY LIGNIN STORAGE/DISPENSING CONTAINERS

Enough lignin will be brought to the lunar surface to complete several structures. To avoid the inefficiencies inherent in storing this amount of lignin in the apparatus, the storage tanks will be of a modular design. They will be fitted on the apparatus upon startup and replaced on becoming empty. Two tanks will be placed on the apparatus at once which will allow continuous operation as each tank will empty at a different time.

These tanks will be cylindrical with a diameter of 1m. and a height of 2m. This gives a volume of $1.6m^3$. Five tanks will be required to make enough materials for one structure. The orifice of the tanks is constructed such that it opens upon placement in the holding apparatus (see figure ?). Before this, the opening is sealed shut by an epoxy material so that none of the lignin material leaks out. The tanks will be of aluminum alloy and have a thickness of 3/16". Small screw converors will be used to transport the dry lignin to the lignin/water mixing chamber.

LIGNIN/WATER SPRAYING SYSTEM

The lunar soil and lignin/water solution mix through a spraying operation. Two pair of nozzles, located on both sides of the orifice connecting the dispensing chamber and mold chamber, spray the soil as it freely flows into the mold. The soil flow rate is 3.33 kg/s and the rate at which the lignin/water solution will be sprayed is 0.6605 gpm.

Spraying the soil as it flows into the mold eliminates the need for a separate mixing chamber and has low power consumption. The "atmosphere" created in the mold chamber is water vapor. This atmosphere is generated by the initial flashing of the water in the lignin/water mixture as it enters the evacuated chamber. With the chamber evacuated at 100^0F (37.8^0C), the amount of water needed to saturate the chamber volume with water vapor is 3.7 g which is 0.15% of the total water being sprayed.

VACUUM DRYING SYSTEM

The time required to dry the brick will be 10 min. if vacuum drying is used. The vacuum needed to accomplish this drying will be provided by the vacuum of the lunar enviornment. The lunar vacuum was chosen because no energy would be required for it to be effective and greater capacity could be obtained than that possible by a mechanical pump. The vacuum on the moon is on the order of 10^{-12} torr. The vacuum effect on the interior of the chamber will be activated after the spraying and vibration processes have been completed. This will be accomplished simply by opening a valve which will allow the contents of the chamber to be drawn out by the vacuum. This valve will be on the outside of a condenser unit which will recover the water from the water vapor as it passes through the condenser unit before this vapor is lost to the outside vacuum. The following assumptions are made in order to use the lunar enviornment is an evacuation source: 1) All vapor not contained in the soil/lignin mixture is immediately evacuated. 2) Due to assumption 1, the drying rate is controlled by the diffusion of vapor through the brick material. 3) The porosity of the brick material is sufficient for a high diffusion rate. 4) The head loss due to the piping in the condenser is negligible.

After the valve is opened, the chamber "atmosphere" is rapidly evacuated, leaving a vacuum around the mold. The water at the surface of the brick, which is exposed to the vacuum will immediately begin to boil.

The water in the interior will travel to the surface through capillary action where it is boiled off and evacuated. This process continues until most of the water is removed. The remainder of the water is removed from the brick as it diffuses to the surface.

WATER RECOVERY SYSTEM

A double-tube condenser which has a height of 1 meter prevents evaporated vapor from reaching the vacuum of the luner environment. The condenser consists of a central pipe, 5cm in diameter and an outer collar. The vapor flows through this pipe and the coolant (N_2) flows in the outer collar. A copper or highly alloyed copper pipe is used as the condenser material. Copper has a very high thermal conductivity and the alloying will add toughness to the pipe.

Condensate will form either as thin sheets of water, film condensation, and as droplets, dropwise condensation. Dropwise condensation occurs at a rate which is approxiamatly ten times more rapid than film condensation. Therefore the condenser is designed to operate under dropwise condensation conditions. For dropwise condensaton to occur, there must be minimal adhesion between the condensate and condenser wall. The inside wall of the condenser piping which the vapor flows through is coated with teflon (permanent promoter) to promote dropwise condensation.

The temperature of the condenser will be held at an average value of 274^0K which is slightly greater than the triple point temperature (273.15^0K). A microprocessor attached to a thermocouple monitors the temperature 20cm above the condenser entrance. With a pump and valves at the entrance and exit, a proper flowrate and local pressure is maintained to provide a reading of 274^0K from the thermocouple

Having a temperature slightly greater than the triple point 20cm up in the pipe assures that the region near the condenser's exit is below the triple point. Below the triple point temperature, water can exist only as a solid or a gas. Water that cannot be condensed out of the vapor into liquid form will be frozen on a copper wire mesh 10cm in length which is located 5cm before the exit. Water in the form of ice accumulates on the screen. Periodically the ice is recovered by isolating the condenser from the lunar vacuum with a valve and heating the condenser with steam from the mold chamber. The nozzles are also purged during this operation as no lignin will be mixed in.

A space radiator cools the nitrogen after it leaves the condenser. The radiator is shaded from the sun and transmits heat in the form of radiation to the lunar night sky. This radiator will also dissipate most of the rest of the heat generated by the small electric motors in the apparatus.

MOLDING AND BRICK EXTRACTING PROCESS

MOLD CHAMBER

The mold chamber is basically a pressure vessel that can be evacuated during the reclaimation process. There will be four chambers, one for each mold. Each chamber will be constructed using A91100 aluminum. The walls of the chamber will have a thickness of .25 cm , except on the bottom of the chamber where it will increase to .62 cm. A large area of the bottom of the chamber will also serve as an exit door through which the finished brick may be extracted. The hatch will include a seal and a pressure lock on the portal so that the chamber can be resealed after brick removal. The wall thickness will increase toward the seal, gradually, so as to prevent stress concentration related failure.

The floor of the mold chamber, which consists partly of the hatch door, will also serve as the actual bottom of the mold. It will be hinged on the long interior seam.

The overall dimensions of the chamber will be 1.2m x .8m x .8m with a section 1.05m x .65m of the bottom floor being a hinged exit door for brick removal. The door will be sealed with an o-ring type seal that will form an airtight barrier while diffusion of the water takes place inside.

MATERIAL

Three basic properties must be considered in order to choose an appropriate mold material: strength, weight, and porosity.

The strength of the mold is important so that the walls will hold under the force of the settling sludge. It must also withstand any fatigue incurred due to repeating the processes.

The weight of the materials being used must be considered. The mold must be as light as possible because of the enormous freight costs to the moon.

After considering these two parameters, strength and weight, the best material suited for these conditions is a Kevlar-epoxy compound. Its strength to weight ratio is more "attractive" than any other feasible material. The Kevlar material has a density of only .8 kg/m^3 and a strength of 2.3×10^8 N/m^2. Thus, its resulting strength to weight ratio is 3.5×10^8 m.

The mold must also be porous so that the water can diffuse out of the sludge and be recovered for later use by the reclaimation process. To achieve a satisfactory diffusion rate, the Kevlar will have a capillary density of at least 100 holes per 6.45 sq. cm of Kevlar. Each hole will have a minimum diameter of .17 cm.

MOLD DESIGN

Two variations of the brick shape will be necessary in order to construct the arched structure, therefore two different mold shapes will be employed. A total of four molds will be used simultaneously by the brick manufacturer, each in its own mold chamber. Three versions of mold A as well as one mold B. (see figs. &) Mold B will have two slanted sides in order to construct bricks for the interior arch.

Mold A will have dimensions of 1m x .5m x .5m with a coner of area .0025 sq. m removed for bolt installation with the structure support strip. (see fig.) Mold B will have dimensions of 1m x .5m x .5m on the bottom lip and dimensions of 1m x .44m x .5m on the top edge of the mold. (fig.) The Kevlar material will be used in a thickness of 1.3 cm , constant around the mold.

The volume of mold A will be .25 m^3 while mold B will have a volume of .38 m^3 .

STRUCTURE

The structure resulting from the completed bricks will require 3021 bricks not including closing off both ends. If it is desired to close off the entire structure, then 4397 total bricks will be needed for a 2m thick covering. The structure is self-supporting, but it will require an aluminum reinforcement strip bolted along the side as well as high strength steel cables at each end. The structure will require 31.87 cu. m of loose soil to packed around the interior arch along the module length. This will insure 2m thickness in small spaces not large enough for a full brick.

The thrust at the bottom of the actual arch, above the vertical supports where the reinforcement strip will be fastened will be 1234 N. The maximum positive and negative moments on the structure are 1428 Nm. [See appendix for details and calculations]

VIBRATOR

The purpose of the vibrator is to insure that the lignin/lunar soil mixture settles to every part of the mold. It will be located at the center of the 1m long side of the mold and will fit flush with the interior of the mold wall. The vibrator will be inserted into the mold while the mixture is entering the mold. It will remain in the mold until all of the mixture has been sprayed in and for a period of time after to insure the sufficient settling has occurred. After the mixture has settled, the vibrator will be slowly removed. The vibrator will run for only a small portion of the molding process (approximately 3 minutes), therefore very little energy will be used. The vibrator will be an electric model similar to those used to settle concrete in the construction industry.

ALUMINUM SUPPORT STRIP FOR ARCHED STRUCTURE

An aluminum alloy (A97075-T6) support strip will be added to the structure on each side at the bottom of the arched portion of the structure, above the vertical brick supports. This material has a yield strength 72 kpsi and a 150 Brinell hardness. It will run along the length of the structure and will control the outward thrust of 1234 N caused by the weight of the arched structure itself. The strip wil be bolted to a plate on the interior of the structure wall and a reinforcement cable will connect each strip at each end of the module [see appendix ? for calculations]. The design of mold "A" has taken the bolting modification into account by excluding a .0025m^2 corner. This allows the bricks to be arranged so that a bolt may pass through the wall without having to drill holes.

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Mr. F Mormon, Sales Representative, Reed Lignin

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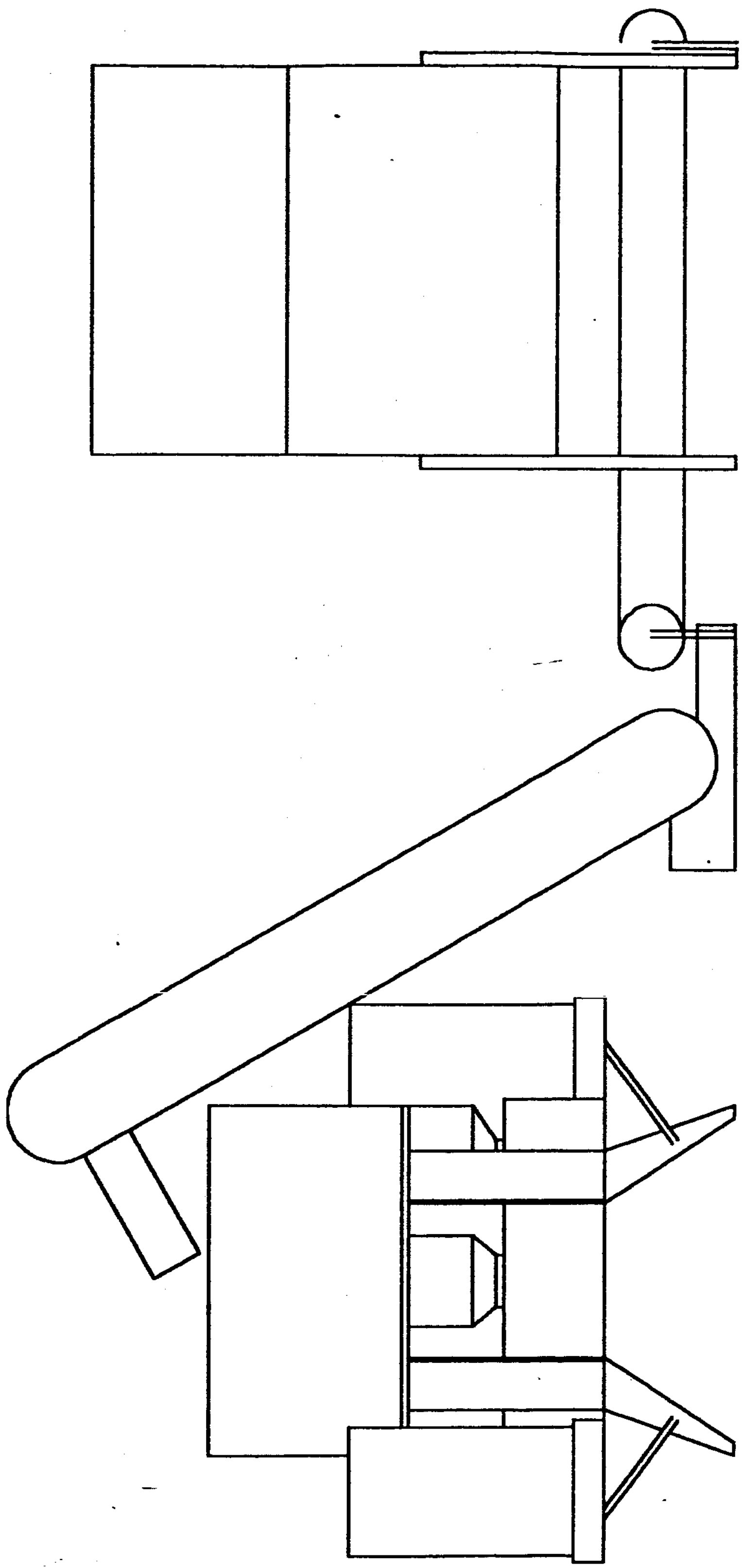

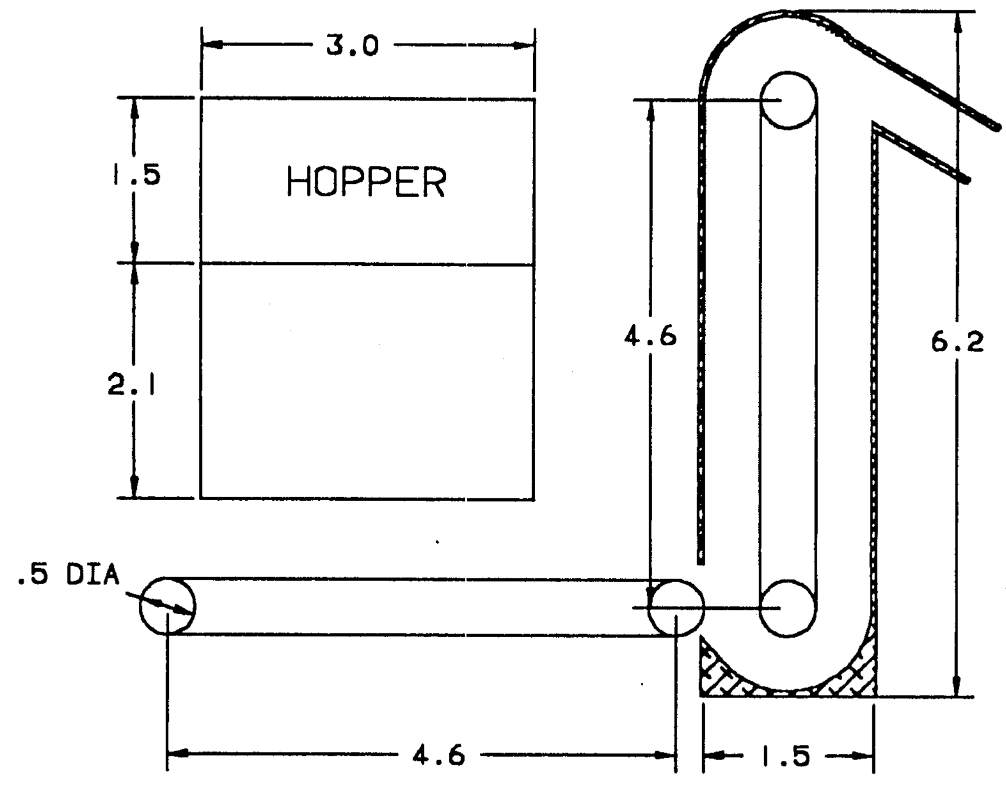

FRONT VIEW

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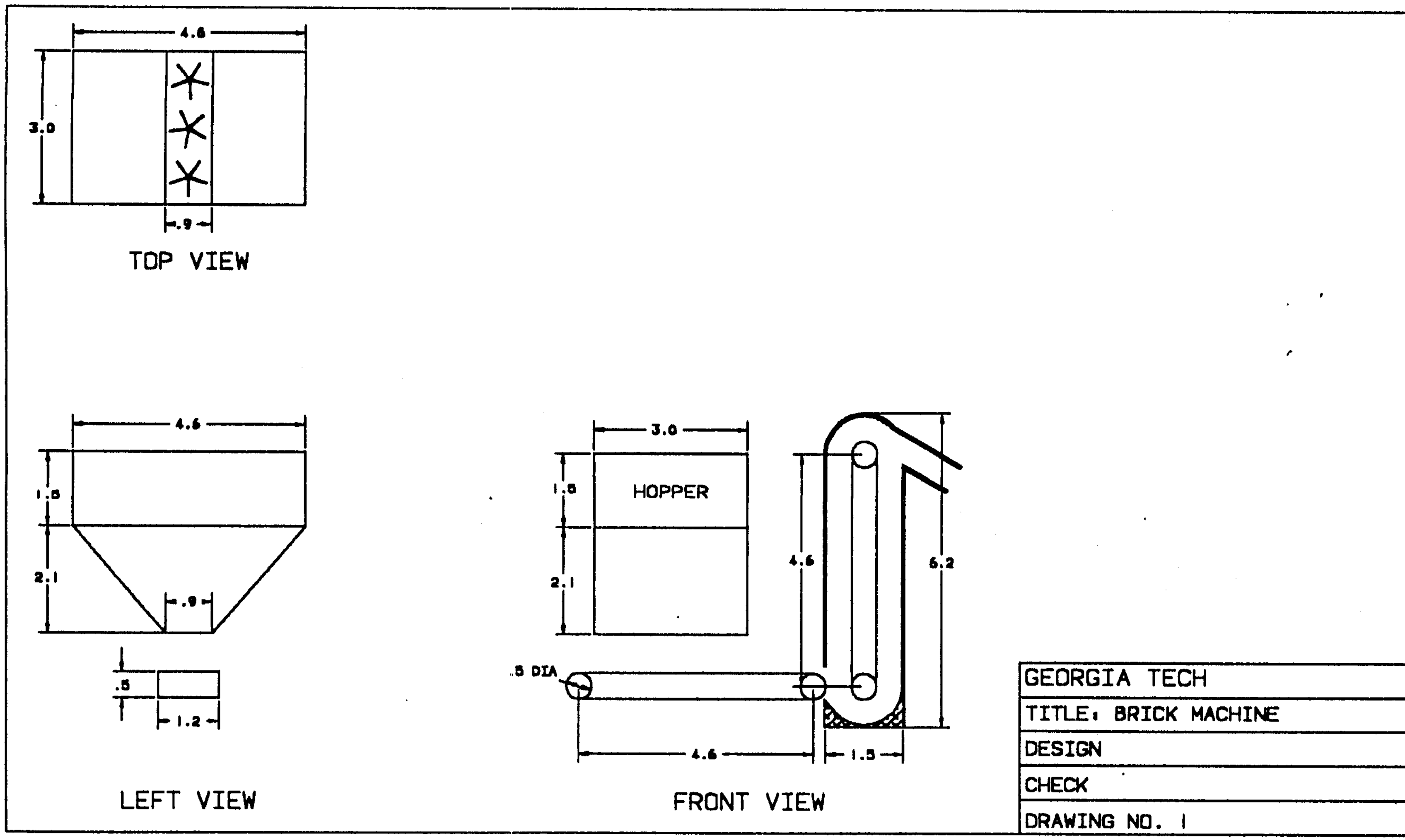
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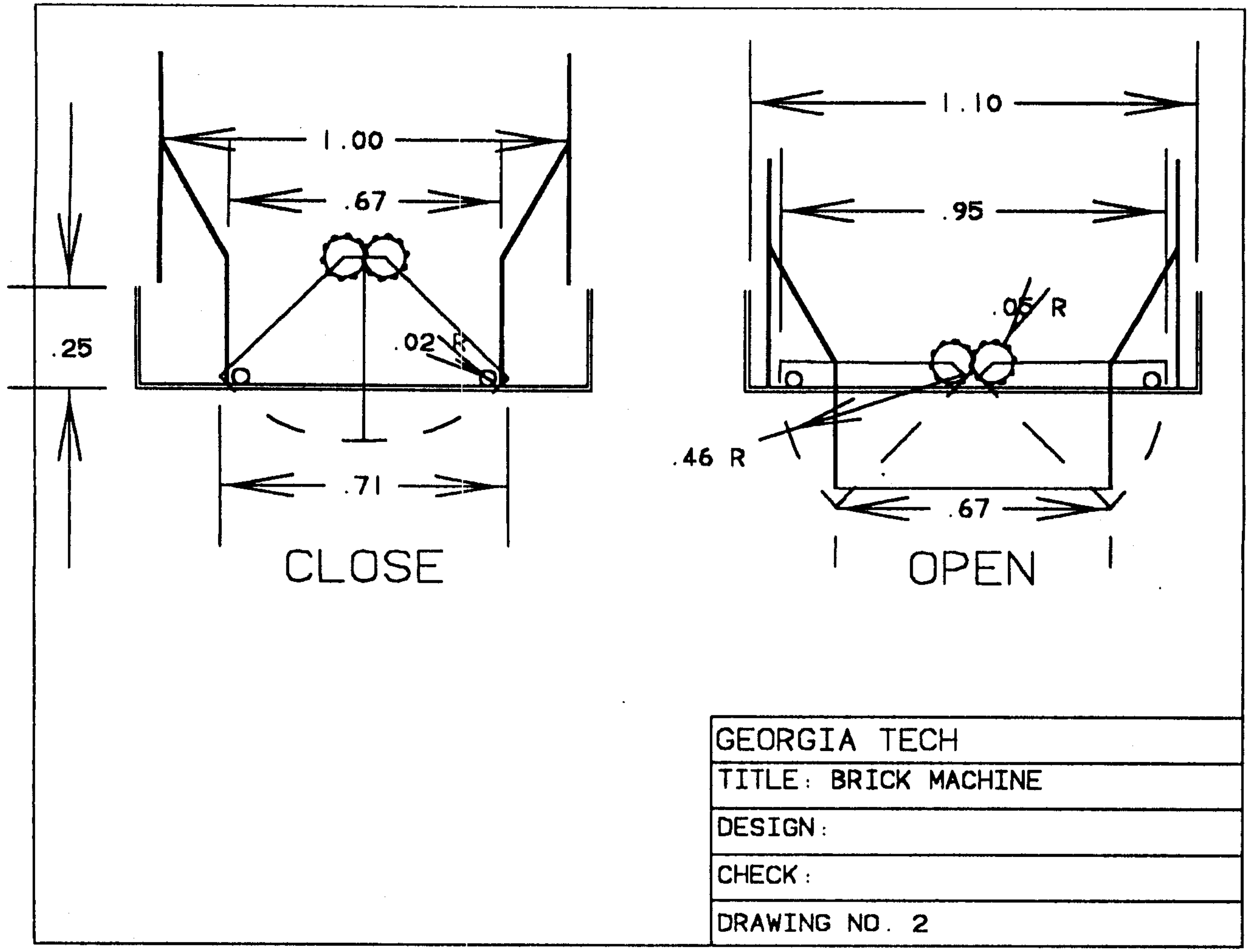
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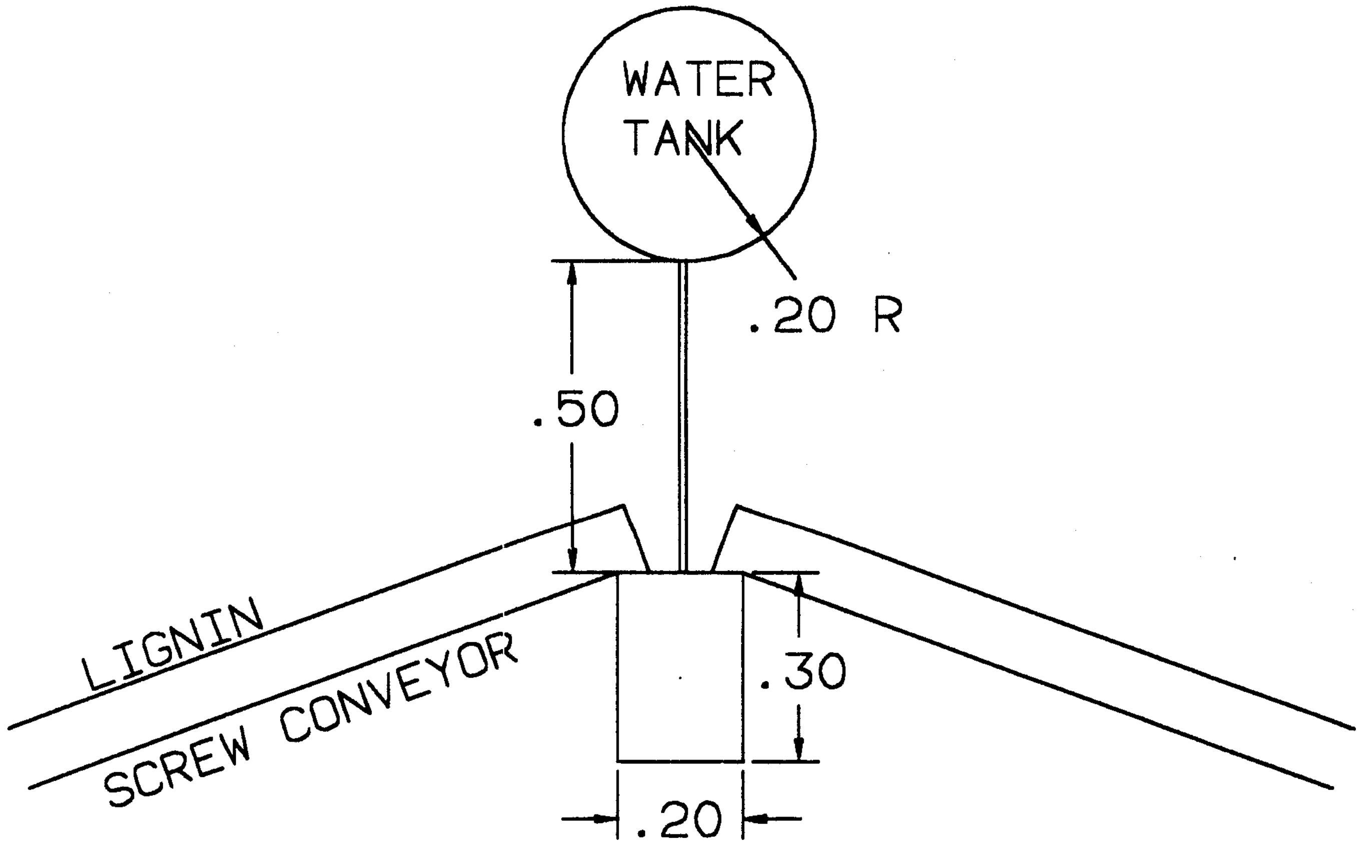

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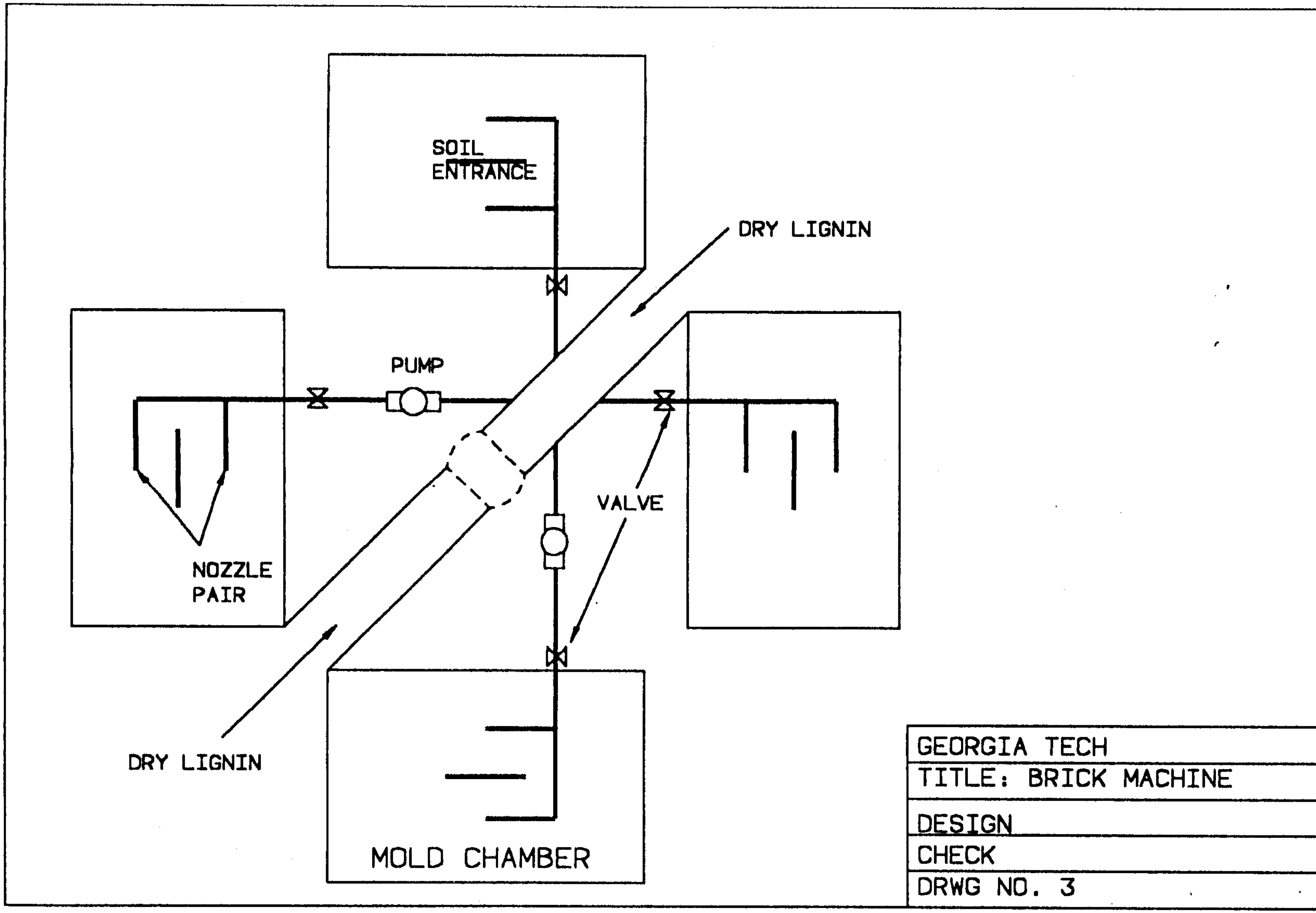
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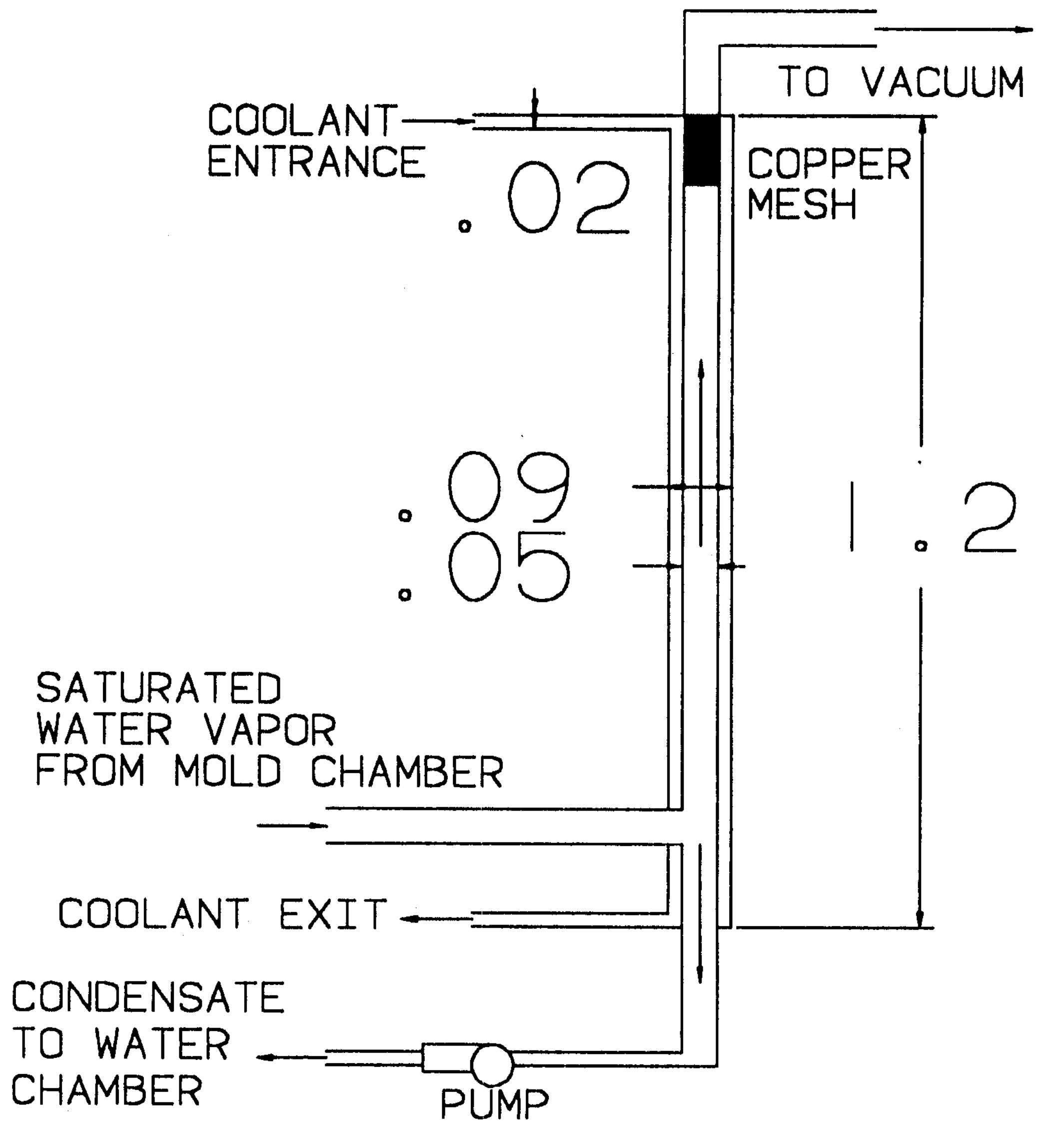

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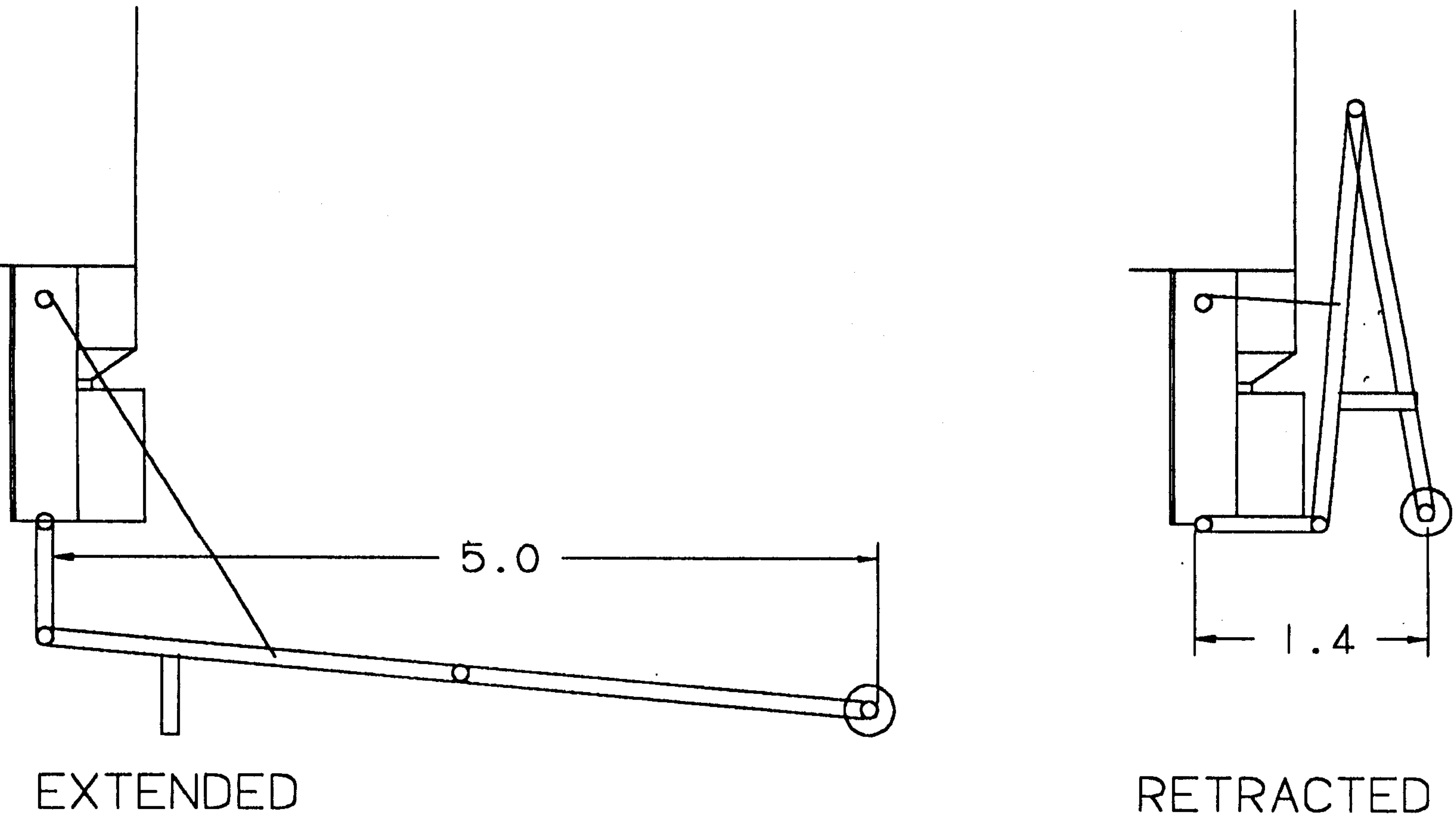
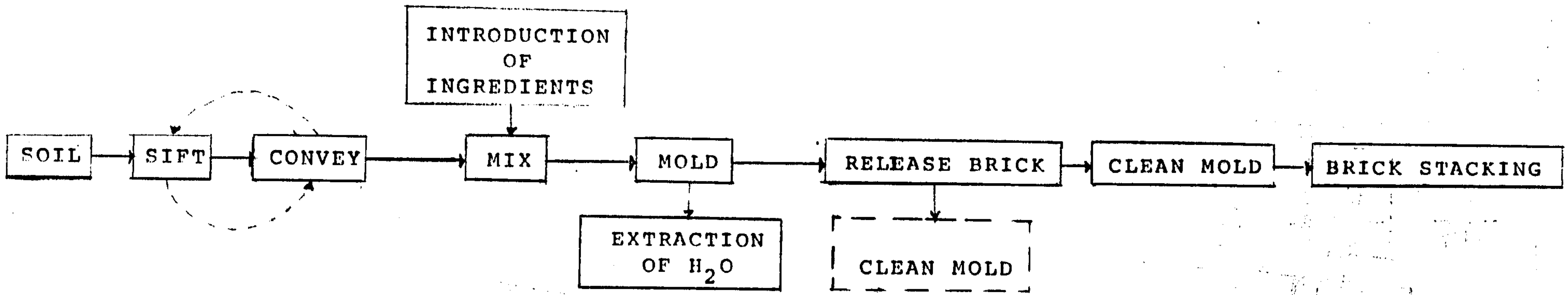


GEORGIA TECH	
TITLE: BRICK MACHINE	
DESIGN:	
CHECK:	
DRWG NO. 5	

APPENDIX A
PROCESS FLOWCHART

LUNAR BRICK MANUFACTURING PROJECT

PROCESS FLOW CHART



APPENDIX B
PRODUCTION MATERIALS, PRODUCTION RATE

PRODUCTION MATERIALS

LIGNOSULFANATE

Lignosulfanates are the soluble derivatives of lignin, a major constituent of wood. The basic lignosulfanate molecule is isolated in the pulping process of paper manufacturing. It is a complex chemical that exhibits some combination of the following properties: dispersing, complexing, stabilizing, co-polymerizing and binding. Binding constitutes the most important property of lignosulfanate for this project. As a binder on earth, lignosulfanate has many uses such as in extrusion, compaction, briquetting, tableting, and disc and drum granulating. As a binder, the lignosulfanate increases the strength and durability of the agglomerate. As a lubricant, it decreases friction between the individual particles in the agglomerate, and between the agglomerate and the forming equipment. This results in reduced wear, lower energy consumption and improved form release. Lignosulfanate also has very stable thermal characteristics as exhibited in the data in appendix ?

LUNAR SOIL

Lunar soil can be described in familiar terrestrial terms as well-graded, silty sands or sandy silts with an average particle size by weight between 0.040 and 0.130 mm (Carrier et al., 1973). The density of *in situ* bulk lunar soil as determined from large diameter core tube samples is tyupically 1.4 to 1.9 g/cm^3. The bulk density increases with depth. Lunar soil also has a very low thermal conductivity (0.0006W/m^{0}C) and a very low thermal diffusivity (7×10^{-10} m^2/s). These properties indicate that convection and conduction are not effective methods of heating the material.

Results have shown that in unconstrained, hard vacuum, the surface friction and strength of rocks, and well-consolidated lunar soil is higher than in a terrestrial. environment. This may be due to greater adhesive (cohesive) forces from higher surface energies and/or due to lack of more than monolayer coverage of water vapor.

REED LIGNIN

P.O. Box 2025
Quebec, P.Q. Canada G1K 7N1
Tel: (418) 694-7800
Telex: 051-3770

81 Holly Hill Lane
Greenwich, Connecticut 06830
Tel: (203) 625-0701
Telex: 643994

GLUTRIN

GENERAL DESCRIPTION

Composition:
Calcium lignosulphonate

Applications:
Foundry cores, refractories, ceramics.

Function:
Binding

TYPICAL ANALYSIS

Chemical Data

7.0	pH
0.0%	Sodium
7.0%	Calcium
0.5%	Sulphate Sulphur
0.6%	Nonsulphonate Sulphur
4.7%	Sulphonate Sulphur
5.3%	Total Sulphur
8.6%	Methoxyl
13.8%	Reducing Sugars

Physical Data

Color: Dark Brown

Powder:
Not available

Liquid:
54% Solids
5.83 lbs. solids/gal concentration at 25oC
300 cps Viscosity at 25oC

Sales Specifications and Material Safety Data Sheets are available upon request.

Compatability
Glutrin is compatible with anionic and nonionic dispersants, wetting agents, fillers and most organic and inorganic materials.

Availability
Liquid solution in 55 U.S. gallon drums, 4000 gallon tank trucks, or 10-20,000 gallon tankcars, is available FOB Rothschild, Wisconsin.

9/85

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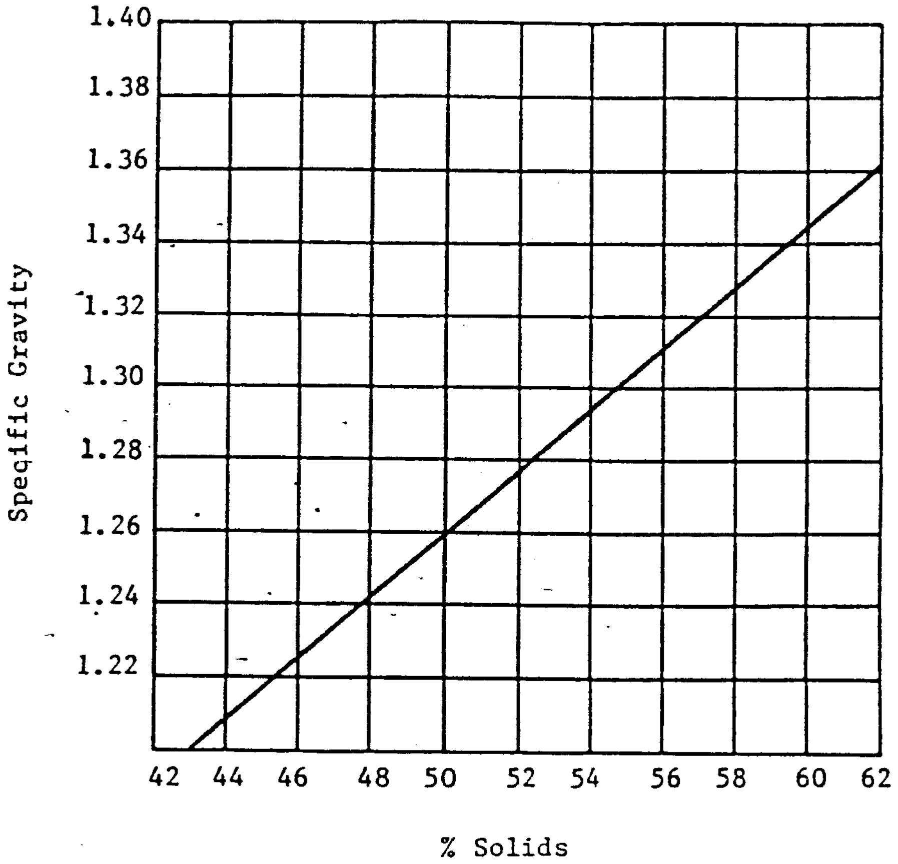
9/85

GLUTRIN

Specific Gravity vs. % Solids



REED LIGNIN

Research and Development
100 Highway 51 South
Rothschild, WI 54474-1198
Tel: (715) 359-6544

HMIS HAZARD RATING:
4 = SEVERE
3 = SERIOUS
2 = MODERATE
1 = SLIGHT
0 = MINIMAL

Fire: 1 | Health: 1 | Reactivity: 0 | Special:

MATERIAL SAFETY DATA SHEET

PRODUCT NAME	GOULAC (Powder)
MSDS NO	File J.3 A-474
DATE PREPARED	1/17/86
SUPERSEDES	All Previous
PREPARED BY	J.W. Adams

EMERGENCY PHONE: (715) 359-6544
CHEMTREC PHONE: (800) 424-9300

I. PRODUCT IDENTIFICATION

COMMON NAME:	Calcium Lignosulfonate	CHEMICAL FORMULA:	Amorphous Polymer
TRADE NAME / SYNONYMS:	See Above	CHEMICAL FAMILY:	Wood Chemicals
MANUFACTURER:	Reed Lignin Inc.	CAS REGISTRY NO:	8061-52-7
DOT SHIPPING NAME:	Lignin Pitch - Class 55	UN NUMBER:	Excluded
HAZARD CLASSIFICATION: DOT:	Not Restricted	IATA:	Not Restricted

II. HAZARDOUS INGREDIENTS

PRINCIPAL HAZARDOUS COMPONENTS	PERCENT	THRESHOLD LIMIT VALUE (units)
NONE KNOWN		

III. PHYSICAL DATA

BOILING POINT (°C)	Not Applicable	SPECIFIC GRAVITY (25° C)	Not Applicable
VAPOR PRESSURE (mm Hg.)	Not Applicable	pH (3% Soln.)	7.0
VAPOR DENSITY (Air = 1)	Not Applicable	BULK DENSITY (lbs./cu. ft.)	35
% VOLATILES BY WEIGHT	6.0% (water)	SOLUBILITY IN WATER	100% Soluble
APPEARANCE AND ODOR	Brown powder with slight odor.		

IV. FIRE and EXPLOSION HAZARD DATA

FLASH POINT (Method Used)	Not Applicable	AUTO IGNITION TEMPERATURE:	400°C for dust
FLAMMABLE LIMITS IN AIR, % BY VOLUME	LOWER: 0.2 oz./cu.ft.	UPPER:	3.5 oz./cu.ft.
EXTINGUISHING MEDIA	Use water spray, carbon dioxide, dry chemical, alcohol-type or universal type foams applied by manufacturer's recommended techniques.		
SPECIAL FIRE FIGHTING PROCEDURES	Use supplied breathing air and protective clothing.		
UNUSUAL FIRE AND EXPLOSION HAZARDS	Flammable solids may provide conditions for a dust explosion.		

Form meets OSHA Standard 29 CFR 1910.1200

REED LIGNIN

Research and Development
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Rothschild, WI 54474-1198
Tel: (715) 359-6544

HMIS HAZARD RATING:
4 = SEVERE
3 = SERIOUS
2 = MODERATE
1 = SLIGHT
0 = MINIMAL

Fire: 0 | Health: 0 | Reactivity: 0 | Special

MATERIAL SAFETY DATA SHEET

PRODUCT NAME	GLUTRIN (Liquid)	NOT OSHA HAZARDOUS	MSDS NO	File L.3 A-487
			DATE PREPARED	11/1/85
			SUPERSEDES	All Previous
			PREPARED BY	J.W. Adams

EMERGENCY PHONE: (715) 359-6544
CHEMTREC PHONE: (800) 424-9300
TELEX: 260091

I. PRODUCT IDENTIFICATION

COMMON NAME:	Calcium Lignosulfonate	CHEMICAL FORMULA:	Amorphous Polymer
TRADE NAME / SYNONYMS:	See Above	CHEMICAL FAMILY:	Wood Chemicals
MANUFACTURER:	Reed Lignin Inc.	CAS REGISTRY NO:	8061-52-7
DOT SHIPPING NAME:	Lignin Liquor - Class 55	UN NUMBER:	Excluded

HAZARD CLASSIFICATION: DOT: Not Restricted IATA: Not Restricted

II. HAZARDOUS INGREDIENTS

PRINCIPAL HAZARDOUS COMPONENTS	PERCENT	THRESHOLD LIMIT VALUE (units)
NONE KNOWN		

III. PHYSICAL DATA

BOILING POINT (°C)	104°C	SPECIFIC GRAVITY (25° C)	1.28
VAPOR PRESSURE (mm Hg.)	14.2 at 20°C	pH (3% Soln.)	7.0
VAPOR DENSITY (Air = 1)	1.21 at 20°C	BULK DENSITY (lbs./cu. ft.)	Not Applicable
% VOLATILES BY WEIGHT	46% (water)	SOLUBILITY IN WATER	100% Soluble
APPEARANCE AND ODOR	Brown liquid with slight odor.		

IV. FIRE and EXPLOSION HAZARD DATA

FLASH POINT (Method Used)	Not Applicable	AUTO IGNITION TEMPERATURE:	Not Applicable
FLAMMABLE LIMITS IN AIR, % BY VOLUME	LOWER: Not Applicable	UPPER:	Not Applicable
EXTINGUISHING MEDIA	Aqueous Solution -- no fire hazard.		
SPECIAL FIRE FIGHTING PROCEDURES	None		
UNUSUAL FIRE AND EXPLOSION HAZARDS	None		

Form meets OSHA Standard 29 CFR 1910.1200

Temperature Effects

Specialty chemicals that find use in oil well drilling, high temperature dyeing and boiler water treatment applications must provide performance at elevated temperatures. Lignosulphonates, which maintain their properties at solution temperatures of up to 220°C (430°F), are widely used in these and similar applications.

Foundry, refractory and face brick manufacturing are among a number of industries that use lignosulphonates to enhance the plastic properties or green strengths of their products during manufacture. In many of these applications the lignosulphonates are later burned off in kilns or furnaces, leaving behind minimal residues.

Thermal gravimetric analyses of different Reed products are shown in **Figure 8.** They illustrate how the degree of decomposition varies with temperature; residues remaining after heating at temperatures between 150°C and 500°C are recorded as percentages of the original material (dry basis).

The viscosity of lignosulphonate solutions is temperature-related. **Figure 9** shows the effect of increasing temperature on the viscosity of a range of Reed products. Even 60% solids solutions are easily handled at modestly elevated temperatures.

Figure 8: Heat Stability Determination via Thermal Gravimetric Analysis

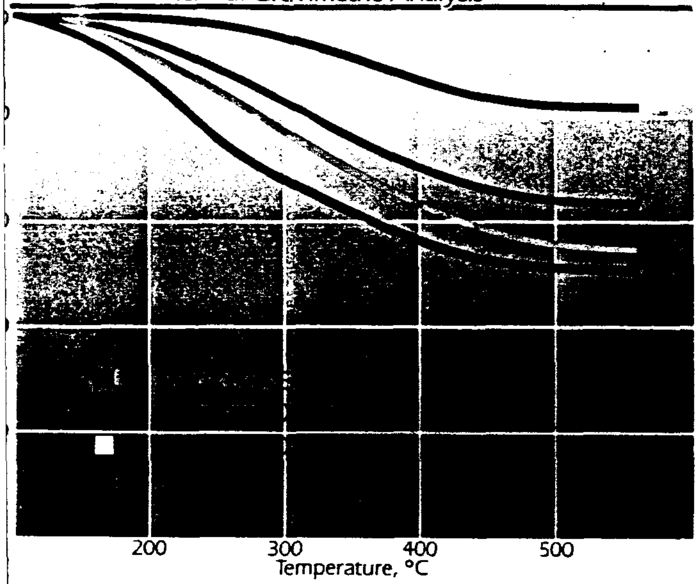
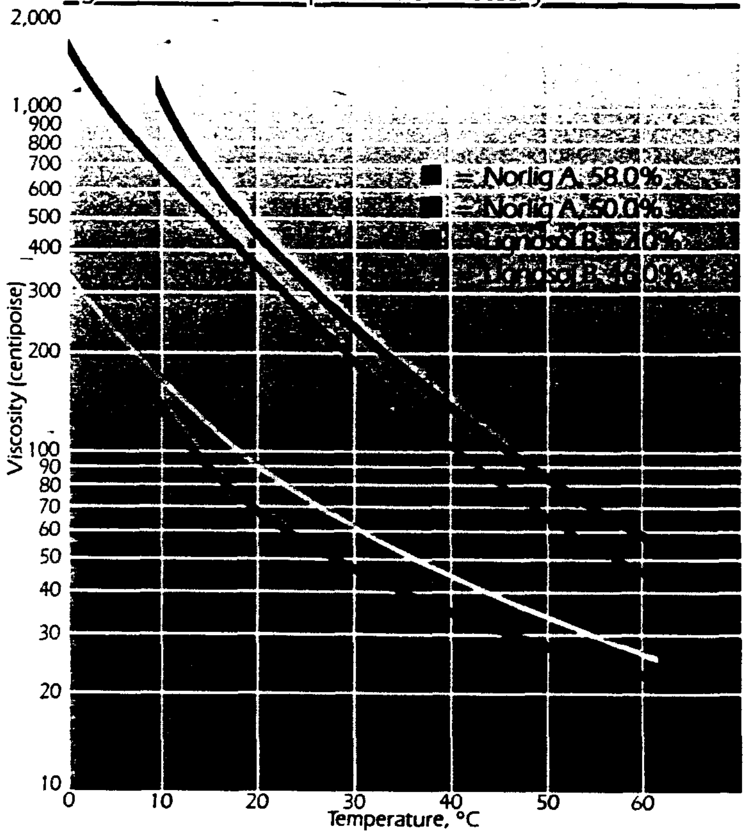


Figure 9: Effect of Temperature on Viscosity



Color

Powdered lignosulphonates range in color from light yellow to dark brown. In solution they appear dark. Generally, unmodified products are light colored; they darken as they are subjected to chemical modification.

In most applications the concentration of lignosulphonate in the end product is so low that color is of no concern. In the dyestuffs and tanning industries, where the color of the end products is important, a light colored lignosulphonate is desired; whereas in animal feed pelletizing and industrial water treatment, a rich brown color is preferred. Dark colored lignosulphonates are also the product of choice in solar pond applications where they maximize heat absorption.

ME 4182
LUNAR BRICK MANUFACTURING

Progress Report
____Week # 2____

Progress this week consisted of eliminating unwanted "brainstormed" concepts. A more in depth study will be conducted on the remaining decisions in each group. These decisions will be reviewed on the basis of theoretical costs and engineering practicality. Team meetings are now being used to coordinate each group's accomplishments to insure compatibility of the final project.

We are investigating industries with parallel task descriptions to our project; such as the coal industry for particle discretion and crushing procedures and various others such as the cement industry for mixing information.

Each group has submitted one or more preliminary designs for their particular stage of the process.

Also, we have obtained computer accounts for both the VMS and the CADAM systems.

SOIL GROUP : (Martin,Toomer)

Limited basic process to sifting and conveying lunar soil, currently researching whether to sift out oversized particles or to crush them (this depends on size estimates), obtained references from "LUNAR BASES" , debated size, power, and weight constraints of apparatus . (1 schematic provided)

MIXING GROUP : (Ingram,Hill)

Made decisions concerning which mixers will not be acceptable, currently researching rake mixers and propeller mixers, examining concept of a two stage mixing process with or without a settling tank to decrease required mixing power. Also researched "LUNAR BASES". (2 schematics provided)

MOLDING GROUP : (Bonjo,Broach)

Decided to use a "teflon type" mold to eliminate the need to clean it after each use, discussed preliminary design for water recovery system, studied "LUNAR BASES" for more information on geology, searched GTECH database for alternative references and dissertations on the latest information, geometric configurations for the brick structure are being experimented with to finalize the mold shape and size. (1 graphic provided)

ME 4182
LUNAR BRICK MANUFACTURING
MAY 8, 1987

TO: Mr. J. W. Brazell
FROM: Lunar Brick Manufacturing Group
RE: Fifth Weekly Progress Report

The group emphasis continues to be size and shape of the actual brick. For additional information concerning this refer to the section on molding.

It was the consensus of the group to seperate the sifting and conveying portions of the process from the mixing and molding. The reasons were height, weight and support, and power.

The brick making process has been finalized. For a complete outline see attachment.

All groups are learning to use the CADAM system.

SIFTING AND CONVEYING: (Martin and Toomer)
Consulted with the civil engineering department for additional information on sieves. It has been decided that two or three 4'x10' overlapping sieves will be used to determine particle distribution of the soil. They will be vibrated by a small motor as an agitating aid. The 3/8 and no. 4 sieves were selected to prevent clogging and machine damage.
The hopper will be a large inverted trapezoid which will allow constant flow of material. Its dimensions are 10' in length, 7' in height, 8' at the top entrance, and 3' at the lower exit. These dimensions will allow for a volume of $385 ft^3$ of lunar soil.
The sieves and motor will be supported by a metal frame.
The conveyor will lie directly under the sieves and transport the desired soil to the mixing chamber. (See sketch 1)
This module will utilize a seperate power source from the mixing and molding components.
Next Steps: Determine size and type of conveyor, power source, material type for hopper, sieves, and supports.

Mixing Group: (Ingram, Hill)
Discussed library search with Mr. Shelton.
Looked into various methods of water recovery from the system. Three alternatives are:

using an outside vacuum,
using desiccants, or
using a closed system.

Devices needed to close the opening into the soil dispenser and molding chamber are being researched. A sliding door type valve that would shut off soil to the system is one choice.
An aperture type opening to seal the system from the outside "atmosphere" is being researched. (See Sketch 2)
Next Steps: Continue research on valves, sealing mechanisms, and water recovery methods.

Molding: (Bonjo, Broach)
Used the architecture library to research parabolic equations for self-supporting arches. The results were taken and used with the computer to plot the experimental equations. Construction of an arch with small scale bricks was done to test stability.
Next Steps: From the computer plot, experiments with several different cutting angles will be made using wooden blocks as bricks.

BRICK MAKING PROCESS

The process needed to make lunar bricks is outlined below.

* Soil is brought to the hopper by the walker
* The soil drains down the hopper through a small opening at the bottom
* As it exits the hopper small particles pass through 2 consecutive sieves; larger ones roll off the sides of the sieve and fall to the ground
* Acceptable material is transported by conveyor to a holding chamber for the mixer
* As the dirt flows through one of four apertures at the bottom of the mixing, chamber it is sprayed with a lignin sulfanate-water mixture then procedes to fall into the molding chamber
* As the molding process begins, the aperture allowing dirt to flow from the holding chamber to the mold is closed
* As the brick is molded, water is extracted from the mold and recycled to be used again
* The finished brick is pushed out of the mold by a sweeping arm onto the moon's surface

LUNAR BRICK MANUFACTURING GROUP

ME 4182

Dr. Brazell

May 15,1987

MIXING GROUP: (Hill, INGRAM)

During the past week we discussed with several professors different ways to evacuate the chamber where the brick is made. In order to conserve energy, it was decided to look strongly at using the vacuum already on the moon to evacuate the chamber. In order to do this we must also look closely at methods to recover the water without losing it to the outside vacuum. Special valving and heat exchangers are being considered to accomplish this.

Also, the method of actuallly transporting the lunar fines within the device is still being investigated but a final design should soon be reached.

Plans for the upcoming week:

We plan to have nearly completed the study fo the necessary thermodyamics involved in the water removal so that a physical system can be designed. The physical design fo the internal lunar transportation should be completed or nearly completed at this time also.

SIFTING AND CONVEYING:(Martin, Toomer)

During the past week this group made several accomplishments . A support configuration for the hoppers and sieves was confirmed. Also, titanium was decided on as to be the material used to make the hoppers, supports and sieves. This was confirmed by Dr. Meyers based on strength, temperature constraints, and density.

The group began to write a rough draft for the final presentation. We worked with the CADAM and MacIntosh for the illustrations of the sifter and conveyor. Several conveyor companies were contacted, however no immediate decisions were made as to which particular conveyor will be used.

Plans for the upcoming week:

We plan to finalize a definite design of the hopper and metering system. We will work with the draft of the final presentation. During next week we plan to make drawings of our hopper, sifters and conveyor. Also, we are working on the determination of the actual mass flow rate.

MOLDING(Bonjo,Broach):

We completed the research on the actual brick size, except for the force diagrams. We determined that each brick will have the following dimensions: 4' x 4' x 1'. From our discussions with Dr. Meyers, titanium will be the material used to make the mold. We also talked with a few professors concerning the ejection of the bricks. Nothing final came from the discussions. The water retrieval system was researched. We had more practice with the CADAM system. We also began to write our first draft for the final presentation.

Plans for the upcoming week:

To complete the force diagrams of the bricks. Work on the process for the ejection of the bricks. At the same time, come up with the process for retrieving the water from the bricks. We will work with the CADAM system to get our drawings of our molds. Also we will continue to work on the draft for the final presentation.

PRODUCTION TIME DETERMINATION

3021 bricks will be necessary to cover a single shelter.

10 days production time will be allotted. 20 hrs. will be allotted per day.

This will allow time for shut downs and for moving of the device.

$$\frac{3021 \text{ bricks}}{10 \text{ days}} \times \frac{1 \text{ da}}{20 \text{hrs}} = 15.11 \frac{\text{bricks}}{\text{hr.}} \approx 15 \frac{\text{bricks}}{\text{hr.}}$$

this is $$0.25 \frac{\text{bricks}}{\text{min}} \quad \text{or} \quad 4 \frac{\text{mins}}{\text{brick}}$$

With 4 molds operating, 16 minutes may be used to fabricate one brick and still remain within the production limit.

SOIL DELIVERY RATE

$$15 \frac{\text{bricks}}{\text{hr.}} \times 0.25 \frac{m^3}{\text{brick}} = 3.75 \frac{m^3}{\text{hr.}} \text{ (lunar soil)}$$

with an overrun factor of 1.5, the upper bin is designed to accomodate approximately $6m^3$ of lunar soil.

APPENDIX C
SIFTING CONVEYING CALCULATIONS

$1.6\ g/cm^3$

Calculations:

Volume of storage vessel:

Bin: $5\ ft \times 10\ ft \times 15\ ft = 750\ ft^3 = 21.3\ m^3$

Hopper: $\left[\frac{1}{2}(3+15)\,7\right] \cdot 10 = 630\ ft^3 = 17.8\ m^3$

Total Volume $= 21.3 + 17.8 = 39.1\ m^3$

Weight of Lunar Soil in Bin

$1600\ \frac{kg}{m^3} \cdot 39.1\ m^3 = 62560\ kg$

density

Initial Shear Stress on Vertical Wall

$\tau_0 = \cancel{\frac{d\gamma}{4f}} \quad \frac{d\gamma}{4(1+\sin\phi)}$

d = diameter of arc opening
γ = density of material
ϕ = angle of repose

$\tau_0 = \frac{(.915\ m)(1600\ kg/m^3)}{4(\cancel{f}+\sin\phi)} = 207\ kg/m^2$

Coefficient of static Friction:

$f = \tan\phi = 1.2$

Normal Force on Vertical wall: $\sigma = \frac{\tau}{f} = \frac{207\ kg/m^2}{1.2} = 173\ \frac{kg}{m^2}$

Velocity of Particle in equilibrium :

$$v_{max} = \sqrt{2gh}$$

g (acceleration on Moon) $\equiv \dfrac{9.6\,\frac{m}{s^2}}{6} = 1.6\,\frac{m}{s^2}$

$$v_{max} = \sqrt{2\left(1.6\,\frac{m}{s^2}\right)(3.7m)}$$

h = height of hopper = $\cancel{3}$.7 m

$$v = 3.4 \text{ m/sec}$$

Coefficient of mobility (freedom of particles)

$$m = 1 + 2f^2 - 2f\,(1+f^2)^{1/2}$$

$$m = .13$$

Note: m = 0 for rigid solids
m = 1 for Newtonian liquids

~~Reg~~

Hydraulic Radius : (R)

$$R = .5(a) = .46m$$

a ≡ opening of bin

Note: greater radius indicates better flow capacity

Developed Shear Stress

$$\tau = \tau_0 + \sigma f = 207 \text{ kg/m}^2 + (173)(1.2) = 415 \text{ kg/m}^2$$

Torque (blade) :

$$F = wL = (28.32\text{ kg}) \cdot \frac{(.43\text{ m})}{2} = 3\text{ kg}\cdot\text{m}$$

Volume ~~per~~ of soil per sector of blade unit

$$\left(\frac{\pi r^2}{5}\right)(\text{width}) = \frac{\pi(.43\text{ m})^2}{5}(.15\text{ m}) = .0177\text{ m}^3$$

Weight per sector : $.0177\text{ m}^3 \cdot \frac{1600\text{ kg}}{\text{m}^3} = 28.32\text{ kg}$

Critical Pressure in Support Columns

$$P_{cr} = \frac{\pi^2 E I}{4L^2}$$

$I \equiv$ moment of inertia

$I = 0.110\,R^4$ for semi-circular cross-section

$(R = 1\text{ ft} = .3\text{ m})$

$E \approx 10\times10^6\text{ psi}$

$$= \frac{(\pi^2)(10\times10^6\text{ lb/in}^2)(.110)(1\text{ ft})^4\left(\frac{12\text{ in}}{\text{ft}}\right)^2}{4(\qquad)^2}$$

$I =$

Throat area of weld

$h \equiv$ thickness of material being welded to the parm

$$A = 1.414\,hd = 1.414(.3\text{ m})(1.22\text{ m})$$
$$= .52\text{ m}^2$$

$d \equiv$ height of weld

$G \equiv$ centroid of weld is at position $x = .3\text{ m}$, $y = .61\text{ m}$

Unit moment of Inertia for Well:

$$I_u = \frac{d^3}{6} = \frac{(1.22\ m)^3}{6} = \frac{1.82\ m^3}{6} = .3\ m^3$$

Speed (r/min) for Sieve Motor:

$$n = \frac{120 f}{P} = \frac{120(60\ Hz)}{2}$$

$$= 3600\ r/min$$

f = frequency
p = # poles

APPENDIX D
MIXING PROCESS CALCULATIONS

CALCULATIONS

SOIL BIN

dia of cylinder = 3.0m
dia of cone = 2.7m

Vcy - Vco = total volume = 6m^3

Vcy = $\pi r^2 h$, Vco = $1/3 \pi r^2 h$

The angle of repose of the lunar soil is approximately 50°
Using a 60° slope for the cone side helps promote soil flow.

$\tan 60^\circ = h_{co}/r_{co}$

r_{co} = 1.35 m
h_{co} = 2.34 m

The cone is truncated to a height of 1.25 m.
The remainder is 1.09m. The radius of a cone this height with a 60° side is 0.628m

The volume displaced by the truncated cone is:

$$1/3\pi[(1.35)^2(2.34) - (.628)^2(1.09)]$$

$$\underline{4.0 \text{ m}^3}$$

The cylinder walls are 1.35 m high
Vcy = 9.54 m^3

Vbin = 9.54 - 4 = 5.54 m^3

SOIL DISPENSER

The soil dispenser holds $0.25m^3$ of lunar soil. The dispenser will be cubical. Dimensions of $.7m \times .7m \times .5m$ give a volume of $.245m^3$ ($\approx .25m^3$) There will be four dispensers. Each of them will have a pyrimidal hopper. For the discharge, 2 minutes time will be adequate. Desired flow rate must be determined in ordre to size the orifice.

$$\frac{0.025m^3 \times 1600kg/m^3}{2 \text{ min}} = 200 \text{ kg/min} \times 1000g/kg \times 1min/60secs$$

$$= 333/3 \text{ g/sec}$$

From Steppenoff fig 8.6, the necessary area of the orifice $\approx 30 \text{ cm}^2$?

[see figure]

LIGNIN STORAGE TANKS

3021 bricks x 0.25m^3/brick = 750m^3 lunar soil

Lignin is 1% by volume of the total material of the brick according to the current information. This gives 7.5m3 of lignin necessary to complete a structure.

A 1m diameter and 2m height are specified for the lignin storage tanks.

The tanks are cylindrical and therefore have a volume of 1.57m^3

This gives 4.46 tanks necessary. This is rounded to 5 tanks per structure.

Bulk density of dry lignin = 35 lbs/ft^3 = 560.62 kgm^3

This gives

680kg lignin/tank--- 1437.63N lignin/tank = 323 lbs lignin/tank

This weight is adjusted for the moon.

For 5 tanks this force gives 7188.15N dry lignin total

Volume of lignin per brick

7.5m^3 total/3000bricks = 0.0025m^3/brick

Volume of H_2O is 1% of total volume also so the volume of water is

.0025m^3

PRESSURE ON WALLS OF STORAGE BINS FOR GRANULAR MATERIALS

Janssen's Equation was used to perform the analysis

?

$$V = \frac{Rw}{\mu' k}\left(1 - e^{-\mu' ky/R}\right)$$

$$L = kV$$

V = unit vertical pressure at any elevation (lbs/ft^2)
L = unit lateral pressure at any elevation (lbs/ft^2)
R = hydraulic radius = Area of cross section/inside perimeter
W = weight of stored material (lbs/ft^3)
μ' = coefficient of friction between material and bin wall
k = ratio of vertical to lateral pressure at any point
A = area (sq ft)
U = inside perimeter (ft)

SMALL SOIL STORAGE BIN
R = 0.75m (2.46 ft)
W=100lbs/ft^3
K = 0.391 (Cauchy pg 21)
μ' = 0.86 (Ketchum pg 126)
y=1.35m (4.4 ft)

L = 130 psi

LIGNIN TANK
R = 0.25m (0.8202 ft)
W = 35 lbs/ft^3
K = .612 (Cauchy pg 21)
μ' = 0.55 (Ketchum p126)
y = 2m (6.5516ft)

L = 49 psi

SOIL DISPENSER
R = 0.17m (0.574 ft)
y = 0.5m (1.6 ft)
all else the same as the small storage bin (upper bin)

L = 41 psi

CALCULATION OF THICKNESS OF GRANULAR STORAGE VESSELS

The formula taken from Ketchum to determine the necessary thickness of granular storage vessels follows:7(pg no)

$$t = \frac{Ld}{2Sf}$$

t = thickness of the plate in inches
h = horizontal pressure in lbs per sq. in.
d = dia. of bin in inches
S = working stress in psi
f = joint efficiency

S can be taken at 16000 psi for the material used (aluminum)
f will be taken at approximately 73 % for a double rivet lap joint

SOIL BIN
L = 130
d = 118 in

t = 0.66 in

LIGNIN TANK
L = 49 psi
d = 39 in

t = 0.08 in

SOIL DISPENSER
L = 4 psi
d = 39 in

t = 0.068 in

Using safety factor of 2

tbin = 1.3 in ≈ 1 3/8 in
tlig = 0.16 in ≈ 3/16 in
tdisp = 0.14 in ≈ 3/16 in

MIXING TANK CALCULATIONS

The design of the tank depends on the volume of water and lignin necessary

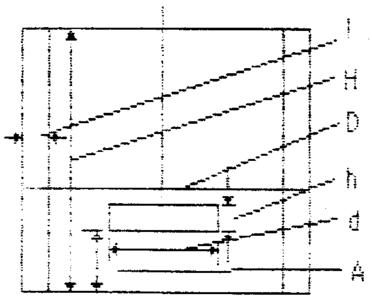
to fabricate the specified number of bricks. The tanks will hold enough

material to fabricate four bricks at a time.
For the laminar region and paddle mixers or turbines with straight or inclined blades under the partial influence of several other geometrical properties, the following relationship is valid

$$No = 0.421\ \Omega n^2 d^3 h/D\ (d/D)^{1.15}\ (HP)$$

No = power input
Ω = viscosity in kg sec/m^2
n = speed (rad/sec)

CONSTRAINTS
H=D , A = H/2, d/D = 0.3 to 0.9
Necessary volume (0.0025 + 0.0025) x 4 = 0.02m^3



A cylindrical mixing chamber is specified

$$V = \pi r^2 h$$
$$2r = h \text{ (specified for design)}$$
Therefore
$$V = 2\pi r^3$$

r = 0.15m D = 0.30m h = 0.30m

d/D = 0.3 to 0.9 (specified for design)
therefore range of d is 0.09 < d < 0.27

let d = 0.2 (2/3 of chamber dia.)

?(neaten)

Assume n = 300 RPM for agitation

300 RPM x 2πrad/rev x 1 min/60 sec = 25 rad/sec
Viscosity of liquid lignin = 300 cps @ 20^o

1 cps = 1×10^{-3} kg/ms
$\Omega = 0.012\ \Omega abs$
Ωabs = 300 cps
$\Omega = 3.6$ kg s/m^2

$No = 0.421\ (3.6)(26.18)^2(.20)^3(0.01/.3)\ (.2/.3)^{1.15}$ HP
$= 0.25$ HP

Note: the mixture will be agitated for 3 min

WATER STORAGE TANK

V_{H20}/BRICK = 0.0025 m^3

For 4 bricks being manufactured at once

V_{H20} = 0.01 m^3 (2.65 gal)/4 bricks

This gives .6625 gal water/brick

Multiply by 1.5 to account for volume in pipes and losses etc.

This gives .0015m^3 H_2O (4 gal)

A spherical tank is specified:

$V = 4/3\ \pi r^3 = 0.015$m^3
$r = 0.153$m (0.502 ft)

Allow 10 % extra volume for freezing during the lunar night

$r \approx .2$m for the spherical tank
volume ≈ 0.02m^3

Thickness of the shell is specified to be 1/4".

DRYING OF THE BRICK

Since there are no drying curves or semiemperical formules for a slab of sand or dand-like material under vacuum conditions, calculating an exact solution of the drying time is impossible. With the use of the following semiempirical formula;

$$Dab = \frac{0.00100T^{7/4}}{P[(\Sigma v)_A^{\ 1/2} + (\Sigma v)_B^{\ 1/2}]^2} \sqrt{1/M_A + 1/M_B}$$

Σv =
P = pressure in atmospheres
T = temperature in Kelvin
M_A=M_B=M=molecular weight of water
D_{AB}= diffusivity of A in B

As the pressure approaches zero, the diffusitivity approaches infinity. This supports the assumption that all vapor not contained in brick immedietely diffuses from the chamber. Although the formula does not determine the diffusivity of a gas through a solid, it suggests that the water in the brick is subject to a rapid boiling due to exposure to a vacuum. An evacuation time of 10 minutes is therefore sufficient.

SCREW CONVEYOR FOR LIGNIN TANK

Design criteria: must be able to meter out 0.01m^3 dry lignin precisely.

0.01m^3 = .3531ft^3

allow 20 secs to complete operation

This gives a rate of 1.059ft^3/min or 0.03m^3/min

This is 1.8m^3/hr or 63.56 ft^3/hr

N is the speed of the conveyor

$$N = \frac{\text{req'd capacity}}{\text{cubic feet per hr. @ 1 RPM}}$$

From Perry's, Table 7-5

$$N = \frac{63.56 \text{ ft3/hr}}{2.8} = 22.7 \text{ RPM}$$

From Table 7-6 ibid

Use 9 in dia screw
allow 1/2 HP
Length ≈ 2m

APPENDIX E
MOLDING PROCESS CALCULATIONS

Appendix calculations : mold and chamber

weight calculations

$$Al : 26.6\ KN/m^3 = 26.6 \times 10^3\ Kg\ (m/s^2)\ /\ m^3$$

$$Volume_{chamber\ material} = (1.2 \times .8 \times .0025)m^3 \times 3\ sides +$$

$$(.8 \times .8 \times .0025)m^3 \times 2\ sides +$$

$$(1.2 \times .8 \times .0062)m^3 \times 1\ side$$

$$Vol = .0164\ m^3$$

$$Wt. = 26.6 \times 10^3\ Kg\ /\ m^2 \times s^2\ (.0164)\ m^3\ (6/9.8)\ s^2/m\ \ (4)\ chambers$$

<u>Wt. = 1068 Kg</u> (moon Kg)

$$Kevlar : 7.84\ KN/m^3 = 7.84 \times 10^3\ Kg\ (m/s^2)\ /\ m^3$$

$$Volume_{mold\ material} = (1 \times .5 \times .013)m^3 \times 2\ sides +$$

$$(.5 \times .5 \times .013)m^3 \times 2\ sides$$

$$Vol. = .0195\ m^3$$

$$Wt. = 7.84 \times 10^3\ Kg\ /\ m^2 \times s^2\ (.0195)\ m^3\ (6/9.8)\ s^2/m\ \ (4)\ molds$$

<u>Wt. = 374 Kg</u> (moon Kg.)

Vibrators = 8 Kg x 4 molds = <u>32 Kg.</u> (moon Kg)

Linkage arms and motors = 15 Kg x 4 molds

= <u>60 Kg.</u> (moon Kg.)

TOTAL WEIGHT = 1068 + 374 + 32 + 60 = <u>1534 Kg.</u> (4 chamber)

Appendix calculations : brick structure analysis

$h_{av} = 4.5m$

$l_{av} = 9.0m$

$w = 653 \text{ N/m}$

$$h / l = 4.5 / 9.0 = .5$$

Thrust $\quad H_2 = w\,(l)\,(.21) = 653 \text{ N/m } (9.0)\text{m } (.21)$

$$= \underline{1234 \text{ N}}$$

Maximum positive and negative moment

x	0	.9	1.8	2.7	3.6	4.5	meters
c	.027	-.012	-.005	.003	.010	.012	
m(x)	1428	-635	-265	159	529	635	Nm

$$M(x) = w\,(l^2)\,(c)$$

$$= 653 \text{ N/m } (9)^2\text{m}^2\,(.027)$$

$$= \underline{1428 \text{ Nm}}$$

Appendix Calculations : structure support

A92011-T3 Aluminum alloy

$$\text{stress} = F/A = 1234 \text{ N} / \pi\,(r^2)$$

$$\text{stress} = S/n = 3.3 \times 10^8 / 3 = 393 / r^2$$

$r = .002m$

diameter = .4 cm

safety factor = 3

BIBLIOGRAPHY